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ABSTRACT With the onset of the COVID-19 pandemic, reports of air quality improvements around the world resulting from the stay-at-home orders were widespread. However, for Chicago, no significant air quality improvements occurred despite large reductions in private vehicle transportation due to the lack of commuters. The city of Chicago is a nexus for long-haul transportation by trucks and trains, which did not decrease during the pandemic. These transportation sources use mostly diesel fuel engines and emit NO_X, a precursor to tropospheric ozone, and $PM_{2.5}$, both of which are harmful air pollutants. Using open access EPA air quality data for the Chicago region, three sites of interest were chosen due to the proximity to the city and location in urban, suburban, and rural areas. The concentration of $PM_{2.5}$ remained elevated at the urban site but not the suburban site during the COVID timeframe, supporting the hypothesis that long-haul transportation emissions dominate poor air quality in Chicago. The suburban site during the COVID timeframe measured statistically significantly higher concentrations of ozone compared to the Non-COVID timeframe most likely due to the complexity of NO_X chemistry and its "lag" effect. This would mean that reductions locally around the suburban site yielded a decrease in concentrations, but the long-haul emission of NO_X around the urban site would lead to the consistent or great concentrations of ozone at the suburban site. While the concentrations of ozone were significantly higher during the COVID timeframe for half of the analyzed months, the site did experience a significant decrease in ozone concentration immediately after lockdown measures were implemented.

INTRODUCTION

As the COVID-19 pandemic was developing there were reports that the smog over major Chinese cities like Beijing cleared, but then returned as shutdowns lifted (Hickey, 2020). The lockdown measures undergone to mitigate the spread of the COVID-19 pandemic effectively ceased the use of some major fossil fuel sources such as passenger vehicle transportation. Early estimates for COVID-19 CO_2 related emissions from road transportation are as high as a 18.6%

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reduction (Liu et al., 2020). This would include passenger vehicle usage decreasing, however there is a lack of passenger vehicle specified transportation and usage studies for 2020 in Illinois.

The transportation sector, including private passenger vehicles, freight, and rail, all produce harmful air pollutants. These pollutant sources produce oxides of nitrogen (NO_X, $NO + NO_2$), which forms tropospheric ozone, and particulate matter 2.5 microns or less in diameter, $PM_{2.5}$. The correlation between human health and these air pollutants has been well studied, contributing to 1-2% excess mortality in populations exposed to air pollutant spikes (Ito et. al., 2005). Additionally, in relation to the COVID-19 pandemic, increases in $PM_{2.5}$ concentration is associated with as much of an 8% increase in COVID-19 death rate (Xiao, 2020). Not only do the failures to prevent air pollution or to prevent the spread of the SARS-CoV-2 virus then lead to higher rates of human mortality, but these two mortality factors then compound in an even more significant failure to keep human populations healthy. A reduction of these pollutants then would potentially result in an improvement in air quality, as well as human lives saved, and therefore served as the pollutants of focus for this study.

$PM_{2.5}$ and ozone enter the atmosphere in fundamentally different ways. $PM_{2.5}$ is a primary pollutant directly emitted from activities such as combustion, and tropospheric ozone is a secondary pollutant, created from atmospheric reactions involving NO_X, volatile organic compounds (VOC), and energy in the form of sunlight (Fig. 1). The differences in the creation of these two pollutants lead to differences in the patterns observed between emission sources and their concentrations. The NO_2 component of NO_X formed can dissociate due to sunlight, resulting in an atomic oxygen (Eq. 1) which ultimately forms the tropospheric ozone (Eq. 2).

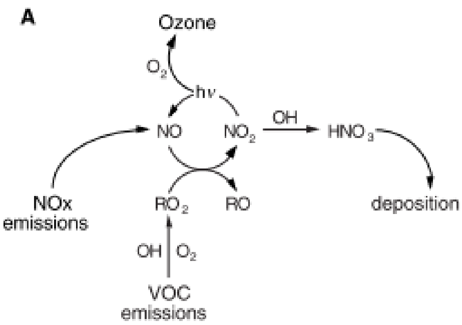

Figure 1. Simplified tropospheric ozone formation schema (Ryerson, 2001).

$$NO_2 + h\nu \rightarrow NO + O \quad (1)$$
$$O + O_2 \rightarrow O_3 \quad (2)$$
$$NO + O_3 \rightarrow NO_2 + O_2 \quad (3)$$

For NO_X and ozone, there is additional complexity since NO also can quench ozone (Eq. 3), resulting in lower ozone concentrations around areas of high NO emissions (Lei et. al., 2014). NO_X will ultimately catalytically form ozone via the mechanism in Fig. 1, but Eq. 3 leads to a suppression of ozone proximate to the NO_X emission source. The quenching of ozone then has implications about the spatial pattern of concentrations. Ozone formation occurs spatially away from the NO_X emission source after the constituents have had sufficient time to react in the atmosphere. This "downstream" ozone formation then occurs in areas that are then not necessarily responsible for the NO_X pollution.

One of the major sources of ozone and $PM_{2.5}$ is fossil fuel combustion for transportation (Thurston, 2008). Unsurprisingly, the stay-at-home orders mandated by countries around the world resulted in transportation reductions. The first shelter-in-place order for Illinois, and more specifically Chicago, was ordered by Governor J. B. Pritzker on March 18th, 2020, requiring those who were experiencing COVID-19 symptoms to stay at home. On March 26th, 2020, a full Stay-At-Home executive order was made, which closed all Chicago parks, beaches, and trails, the Chicago Riverwalk, and the Bloomingdale Trail. Six feet of social distancing was required and get-togethers of more than ten people in public or at home were prohibited (COVID-19 Orders). In relation to the pollutants under investigation, the requirement for citizens to remain indoors then had secondary effects such as less road traffic for private transportation. Public transportation changed less. Even with a 70% decrease in ridership, the Chicago Transit Authority, responsible for the city's public train and bus system, has maintained pre-COVID services using funding from the federal Coronavirus Aid Relief Economic Security (CARES) Act (Garcia, 2020). While official transportation numbers were not available for this study for the City of Chicago, traffic along the Illinois Tollway dropped to 45% of normal passenger vehicles and 80% of normal commercial traffic (Rumore, 2020). Given the experience of China and other countries, the expectation is that stay-at-home orders of this magnitude would then yield significant reductions in ozone and $PM_{2.5}$ (He, 2020).

$PM_{2.5}$ concentrations were measured around the world and found to have decreased due to the lockdown measures (Chauhan, 2020). During the first quarter of 2020 compared to the same quarter in 2019, there was a significant decrease in concentrations of other pollutants as well as $PM_{2.5}$ in some US states during the pandemic (Shakoor, 2020). However, other studies for metropolitan areas in the US found that stay-at-home orders had negligible impacts on air quality (Jia et. al., 2020). In Chicago, a lack of air quality improvement observed in preliminary EPA data raised the issue as to why pollutants such as ozone and $PM_{2.5}$ did not decrease as expected. An article in the popular press hypothesized that the lack of reduction was due to Chicago being a central hub for long-haul transportation across the country (Hawthorne, 2020). Freight trucks and rail contribute significant amounts to total NO_X and PM emissions (*National Emissions Inventory (NEI) Air Pollutant Emissions Trends Data, 2010*). Since the movement of goods continued during the pandemic, long-haul transport could account for the lack of reduction in pollution concentrations (Hawthorne, 2020).

To test this hypothesis, we examined the spatial and temporal trends of ozone and $PM_{2.5}$ before and during the pandemic using archived high-quality EPA air pollutant data, as opposed to the preliminary data provided in near real time. If the hypothesis is correct, the urban site should show no change in air quality, since it is dominated by long-haul truck and train sources. But a more suburban site further from the transportation hubs within the city of Chicago should show an improvement in air quality during the pandemic. This site would be more affected by passenger vehicle emissions and local traffic. These predictions should be most clear for $PM_{2.5}$, since it is a primary pollutant. Ozone is more complicated, since it is produced in a non-linear process from NO_X emissions.

METHODS

To understand the COVID-19 pandemic air quality trends in the city of Chicago, freely accessible, open-source data were employed for all analyses.

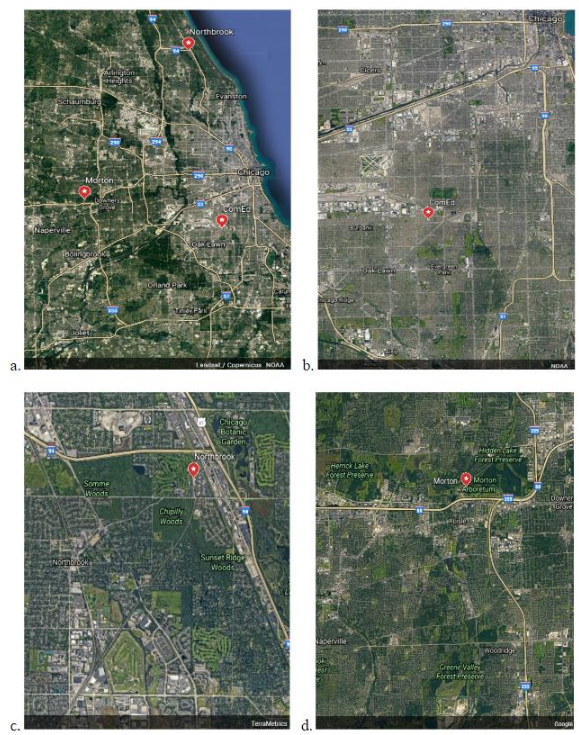

Figure 2. a. Location of all three air pollution monitor sites for this study. b. Location of the ComEd 0076 monitor site 41.7513, -87.7130. c. Location of the Northbrook 4201 monitor site 42.1611, -87.7868. Location of the Morton 6001 monitor site 41.8366, -88.0656.

The data used for this completely remote study is downloadable directly from a web API provided by the US EPA. R and RStudio were used to conduct the analyses. Three sites of interest were chosen: ComEd (EPA Site 0076), Northbrook (4201), and Morton (6001) (Fig. 2).

These sites were selected given their proximity to the large metropolitan center of Chicago and the respective urban and suburban locations of the ComEd and Northbrook sites, and the Morton site with more rural influences given prevailing westerly winds. From the available US EPA data for the three sites, reported values from 2015-2020 were extracted for the pollutants $PM_{2.5}$ (parameter codes 88502 and 88101 separately) and ozone (44201), with the data from the four years prior to 2020 being considered sufficient for a stable pre-COVID-19 baseline (Jia et. al., 2020).

Two different $PM_{2.5}$ parameter codes were found in the EPA, both which have the same measurement and reporting method, but different instruments and levels of quality control. Parameter code 88502 for ComEd was listed as “final” data, while for parameter code 88101 for Northbrook was listed as preliminary data. However, both sites reported some negative concentrations of $PM_{2.5}$ which is particularly surprising for the “final” status of the ComEd data. The Morton site did not report any $PM_{2.5}$ data for any of the potential $PM_{2.5}$ parameters. The maximum amount of data available for these two sites was from December 1st 06:00AM 2016 to August 26th 14:00PM 2020. The Northbrook data set had been already trimmed to exclude outliers greater than 45 ppm, to which the ComEd data set was then also trimmed to exclude outliers greater than 45 ppm removing about 6.2% of the total data. By visual inspection the outliers at the ComEd annually occurred on or around July 28th. We then operated under the assumption that the outliers experienced around this date were due to either instrument error or maintenance of the instrument.

Given that ozone concentrations generally do not reach concentrations that are high enough to be harmful to most human populations during the winter, the US EPA ceased reporting data during the months of November through February. Data then was reported from March 1st 00:00AM through October 31st 23:00PM starting in 2019. Approximately 90% of the data available was available in 2019 whereas in 2020 roughly 80% of expected data was available. The missing data was due to system malfunction or downtime (P. Banerjee, Cook County Department of Environment and Sustainability, personal communication) All data extracted on a yearly basis was then trimmed across all three monitor sites to only consist of reported values from March 1st 00:00AM through October 31st 23:00PM.

Non-COVID data was in the span from 2015-2019 and COVID data being all data in 2020. The time frame designated as COVID for this study does include the months of January, February, and March for $PM_{2.5}$, even though the city of Chicago did not implement COVID-related restrictions until mid-March. Since the US EPA ceased reporting data during the Winter months of November through February, there are 18 days at the beginning of March described as COVID data prior to the first public health order by the city of Chicago for ozone. For ozone the peak hours were identified by inspection of diurnal cycles. Differences in location and time (annually and monthly) at the three sites were considered as the drivers for significant differences in emissions. A lineal model, a method of analyzing relationships between variables, was used to determine the difference in measure pollutant concentrations between two sites in relation to a certain time factor, year or month. This helped to establish the temporal trends in the measured differences between sites. Furthermore, a student’s t-test was used to determine significant differences between sites purely off the spatial differences, therefore without the influence of temporal changes.

R version: 4.0.2 (2020-06-22) – “Taking off Again”
RStudio version: 1.3.1093 (2020-09-17) – “Apricot Nasturtium”

RESULTS

$PM_{2.5}$

The shared variance between the ComEd and Northbrook sites was just above 26%, meaning the ComEd and Northbrook sites experienced different concentrations for 74% of the data, due to the spatial differences between sites (Fig. 3).

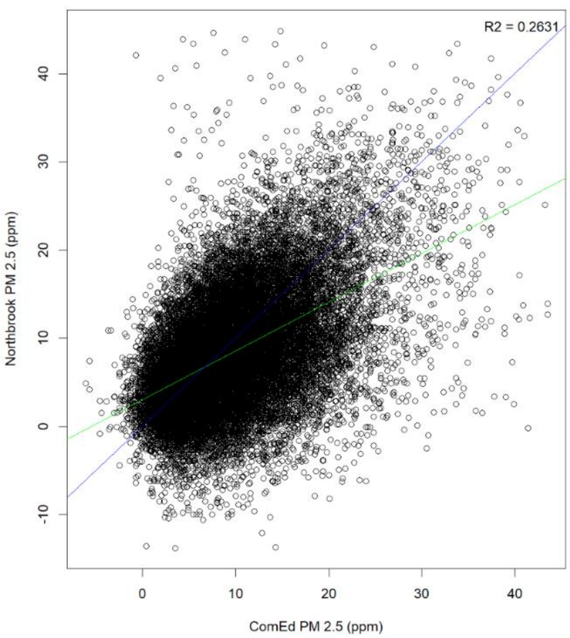

Figure 3. The raw data correlations between the two $PM_{2.5}$ sites; ComEd and Northbrook. The blue line represents a perfect correlation (one to one slope), whereas the green line is the fit that best represents the data.

Note that because of the trimming done to remove outliers, there are no high values in the correlation. This would support spatial variation between the sites as even the baseline concentrations measured were 74% different. By inspection, concentrations did not vary systematically diurnally or annually and rather were relatively consistent with outliers also somewhat consistent in number, temporal trend, and magnitude (Fig. 4). The medians, upper, and lower quartiles (where 25% of the values are smaller than the upper quartile and 75% are larger than the lower quartile respectively) of these box and whisker plots tend to be consistent through the day. The whiskers, with a positive range, extended to the most extreme data point that is less than or equal to the range times the interquartile range, difference between upper and lower quartiles, from the box. The upper and lower extremes also tend to be consistent by the hour. The monthly box and whisker medians are also relatively consistent with variant maxima for the outliers.

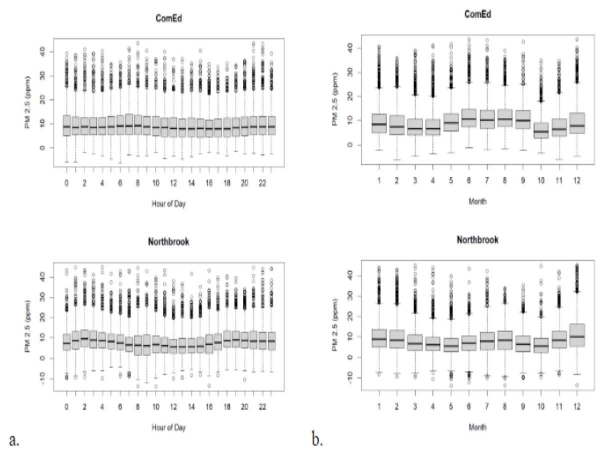

Figure 4. a. $PM_{2.5}$ hourly medians. b. $PM_{2.5}$ monthly medians.

For both the Non-COVID and COVID timeframes, the Northbrook site had significantly higher concentrations than the ComEd site, however during the Non-COVID timeframe this occurred in February, whereas during the COVID timeframe this occurred in January (Fig. 5).

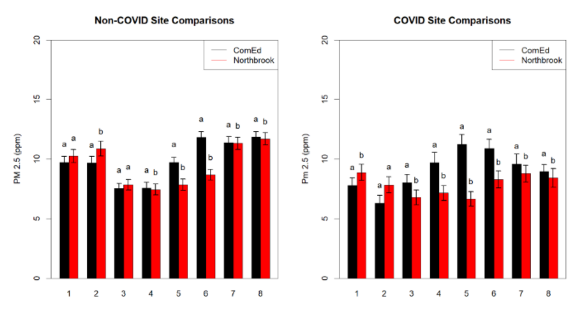

Figure 5. Site comparisons and listed significant differences between sites based on $PM_{2.5}$ concentrations for the COVID and Non-COVID timeframes. Lettering above the bars represent significant differences, as similar letters reflect no significant difference, and dissimilar letters are significant differences determined via t-test.

Additionally, for 5 of the 8 months during the Non-COVID timeframe the ComEd site was significantly greater than the Northbrook site (t-test, $p \leq 0.000864$), but during the COVID timeframe, the number of these months increased to 6 of the 8 being significantly greater (t-test, $p \leq 0.00372$) (Fig. 5). The spatial PM2.5 concentration difference between the two sites therefore got larger going from the Non-COVID timeframe to the COVID timeframe.

The most notable result is the marked differences between the Non-COVID time frame having consistently higher concentrations of $PM_{2.5}$ than during the COVID time frame at the Northbrook site for 6 of the 8 months (Fig. 6).

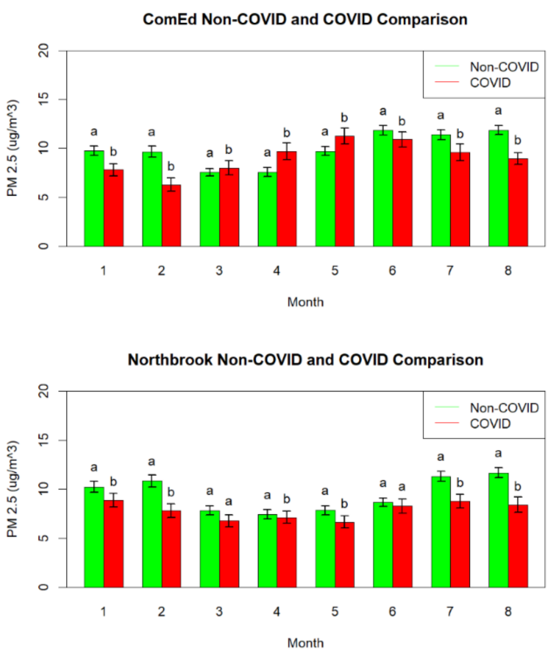

Figure 6. $PM_{2.5}$ Non-COVID and COVID timeframe comparisons per month on a per-site basis.

This would suggest that the COVID stay-at-home orders did improve the air quality at Northbrook. Juxtaposed with the ComEd site, there is an increase in COVID $PM_{2.5}$ concentrations to the extent that the COVID concentrations were significantly greater than the Non-COVID concentrations, creating a further spatial difference of concentration experienced between the two sites (Fig. 6). During March, April, and May, there were significantly greater concentrations of $PM_{2.5}$ during the COVID time frame than during the Non-COVID time frame at the ComEd site (t-test, $p \leq 0.0106$), whereas at Northbrook the concentrations were either the same in March, or the Non-COVID time frame had greater concentrations than the COVID timeframe (t-test, $p \leq 0.0201$), (Fig. 6). Lettering above the bars reflect no significant difference, and dissimilar letters are significant differences. The ComEd site was then the singular site which measured higher concentrations during the COVID timeframe for $PM_{2.5}$.

Ozone

The three sites shared at least 73% of variance, and therefore there is a strong degree of regional-spatial concentration coherence (Fig. 7).

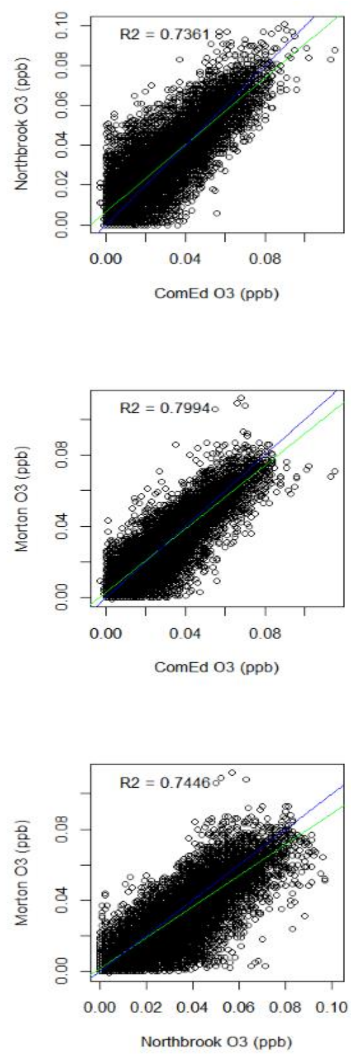

Figure 7. The raw data correlations between the three ozone sites. The blue line represents a perfect correlation (one to one slope and zero intercept), whereas the green line is the linear best fit.

This means that the two compared sites only differed for 27% of the data. However, the outliers, which correspond to the greatest human health impacts, do not occur simultaneously at the different sites. Thus, the data share the same general pattern of ozone concentrations but differ in when spikes occur.

For example, the high concentrations at the Morton site correspond to lower concentrations at the ComEd site, and vice versa. The time of day in which ozone concentration typically peaked was from 11:00AM – 5:00PM (US Central Standard Time, Fig. 8). Peak ozone concentrations are of most interest since that corresponds to the most harm to humans (Lippmann, 1991). The average nighttime concentrations of ozone across the three sites were 0.020 - 0.025 ppm, which increased to concentrations of 0.030 – 0.0375 ppm during the day across all three sites (Fig. 8).

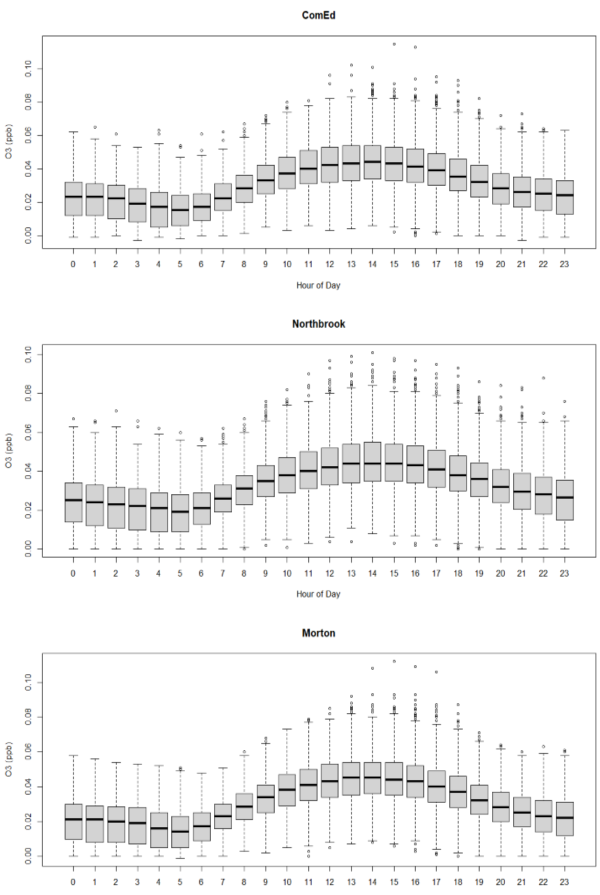

Figure 8. Ozone hourly medians across 2015-2020 for the three monitor sites. The upper and lower extremes also tend to follow similar hourly patterns with outliers tending to occur during peak ozone hours across the three sites.

The Northbrook monitor site had significantly higher concentrations of ozone for 4 of the 7 months in the Non-COVID timeframe compared to the ComEd and Morton sites (t-test, $p \leq 0.00378$) (Fig. 9). Additionally, Northbrook had significantly higher concentrations of ozone compared to Morton for all months (t-test, $p \leq 0.0404$) (Fig. 9). The ComEd site and Morton sites flipped in higher ozone concentrations from the Spring into the Summer. The Morton site overall was relatively stable in ozone concentration for the Spring and Summer months until August where marked decreases in concentration occurred. The spatial differences in concentrations in ozone during the Non-COVID timeframe then served as the baseline to compare to for further analyses.

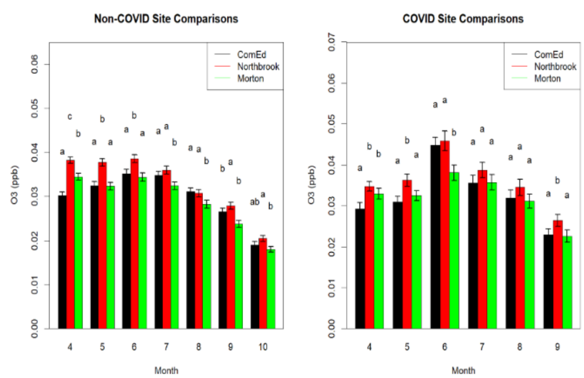

Figure 9. Site comparisons and listed significant differences between sites based on ozone concentrations for the COVID and Non-COVID timeframes.

For the COVID timeframe, the Northbrook site only measured statistically higher concentrations of ozone than both of the other two sites for 2 of the 6 months (t-test, $p \leq 0.00378$) (Fig. 9). The ComEd and Morton sites measured concentrations of ozone that were not significantly different for 4 of the 6 months during the COVID timeframe whereas during the Non-COVID timeframe these two sites had concentrations that were not significantly different for only 3 of the 7 months. This would suggest that the ozone concentrations at the ComEd and the Morton sites became more similar going from the Non-COVID timeframe to the COVID timeframe. All three sites continued to measure statistically the same ozone concentrations in August, and then the Northbrook site had significantly greater concentrations in September (t-test, $p \leq 0.00128$), where the ComEd and Morton sites once again did not have significantly different concentrations.

For April, the height of the lockdown, only the Northbrook site had a significantly higher ozone concentration during the Non-COVID time compared to the COVID time, and in June there was an increase in ozone concentration during the COVID timeframe across all three sites (Fig. 10).

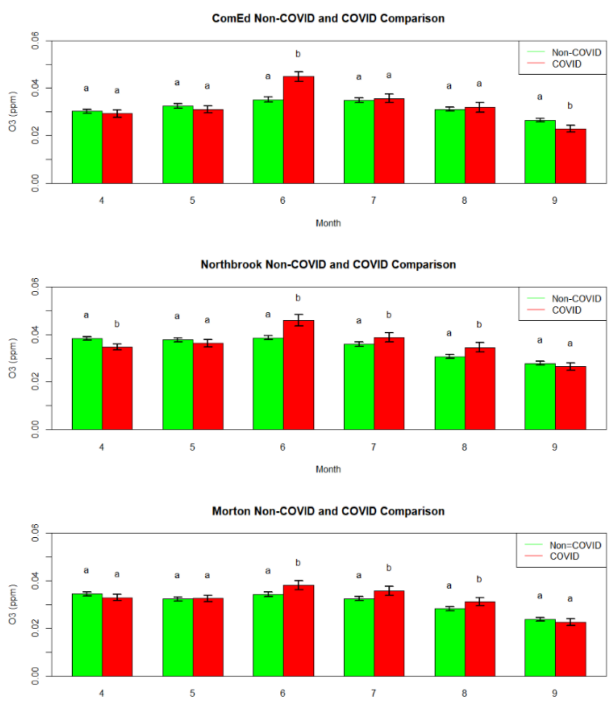

Figure 10. Ozone Non-COVID and COVID timeframe comparisons on a per-site basis.

Overall, the ComEd and Northbrook sites had significant differences that were greater in magnitude compared to the Morton site. For the Summer months of June, July, and August the measured ozone concentrations were higher during the COVID timeframe than the Non-COVID timeframe across all three sites (t-test, $p \leq 0.00833$), although the difference was not always significant. The pattern changed for August where Non-COVID ozone concentrations were once again significantly higher than COVID concentrations for the Northbrook and Morton sites (t-test, $p \leq 0.00833$) (Fig. 10).

DISCUSSION

The decreases in overall transportation did not result in consistent reductions in ozone and $PM_{2.5}$ at the three sites in this study, providing the potential to support the hypothesis that the lack of improvement to air quality is linked to long-haul transport diesel emissions going through the city. However, where reductions in $PM_{2.5}$ and improvements in air quality did occur, they occurred at the Northbrook site. For example, $PM_{2.5}$ concentrations were significantly lower for 4 of the 6 months after lockdown began in March (Fig. 6). Furthermore, the Northbrook site was the only site that experienced an initial significantly lower ozone concentration in April, immediately after lockdown measures were instated (Fig. 10). This is consistent with our hypothesis, since the Northbrook site outside the city would be less impacted by long-haul transportation sources.

The differences we observed at the ComEd and the Northbrook sites during the COVID timeframe can potentially be attributed to the long-haul transport of goods into the city of Chicago. While somewhat speculative, the transport of goods into the city would need to continue through the pandemic to support the large population. A more direct study focusing on the flux of goods during the pandemic, specifically in metropolitan areas, should be of interest for determining the air quality in cities during the pandemic. For our study, the concentrations of $PM_{2.5}$ either remained consistent or rose compared to the Non-COVID timeframe during the initial lockdowns at ComEd. In contrast the Northbrook site measured concentrations of $PM_{2.5}$ that were more often significantly lower than during the Non-COVID timeframe. This supports the claim that air quality in Chicago did not improve as observed in some other cities, and rather worsened immediately as lockdowns began.

For the Northbrook site, a potentially confounding variable is road construction occurring on nearby residential streets as well as the major highway, I94, during a large portion of the study timeframe (2016 – 2020, Fig. 11) (Asphalt Street Resurfacing Program - Summer 2020: Northbrook, IL, Concrete Street Panel Replacement - 2020: Northbrook, IL). Measured concentrations of $PM_{2.5}$ could have been influenced by the local road construction in the area and not necessarily be representative of regional $PM_{2.5}$ concentrations. Construction in the Northbrook area may have contributed to variations in $PM_{2.5}$ concentration measurements. Hypothetically, the decrease in $PM_{2.5}$ at Northbrook could be due to a slowdown in construction activity during the COVID timeframe. While construction projects were not prohibited during COVID, this is a possibility.

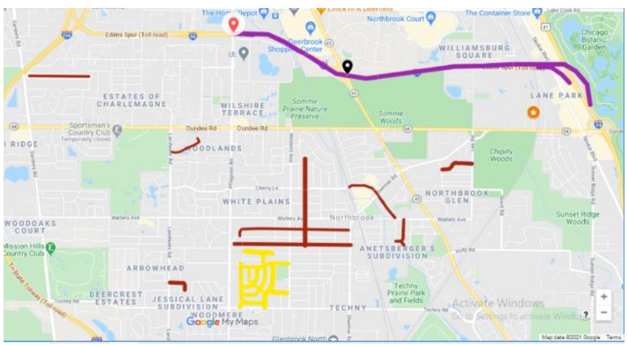

Figure 11. The orange star icon reflects the Northbrook monitor location. The I94 highway region highlighted in purple underwent major asphalt replacement since 2018. The black marker towards the center of the purple highlight are the Waukegan Road Bridge repairs, and the pink highlight on the western most end of the purple highlight is the Pflingsten Road Bridge replacement. Roads highlighted in red underwent asphalt resurfacing, whereas the roads highlighted in yellow underwent concrete panel replacement. The Northbrook monitoring site is within a 4-mile radius from the main areas of road construction just South of the White Plains neighborhood.

Since the ComEd site is urban, the concentration of NO, a precursor to tropospheric ozone, is anticipated to be greater due to more emission sources nearby. However, greater NO concentrations do not necessarily lead to higher ozone concentrations in the immediate vicinity of NO emission sources. Quenching via Eq. 1 suppresses ozone concentrations near NO sources. Rather, NO_X cycling requires time, UV light during daytime hours, and volatile organic compounds to create ozone ([NRC], 1992, Ryerson, 2001 and Figure 1). This sort of "lag" between the source of an ozone precursor and the creation of the ozone results in a spatial effect between the two areas. This then can be attributed to the significantly higher concentrations we observed with the Northbrook concentration compared to the ComEd and Morton concentrations in April, May, and June, both during and before COVID (Fig. 9).

Interestingly there was also a rapid increase in ozone, a spike, at the ComEd site in June of the COVID timeframe (Fig. 10). This spike in ozone at the ComEd site could potentially be the result of a premature effort by Chicago to gradually resume back to "normalcy" in the form of another public health order effective July 24th 2020 reopening businesses. Reopening prematurely would then result in an increase in private transportation due to services being offered, providing more pre-cursor for ozone creation. Note that this requires further investigation into private transportation increases in the city due to this premature resumption of normalcy as well as if that would manifest as the abrupt spike that was observed. The premature efforts to return to "normalcy" leading to the lack of improvements in air quality were not a focus of this study in particular.

Another possible explanation for the lack of decrease in air pollutants in Chicago during the pandemic could be the long-range transport of ozone precursors and $PM_{2.5}$. The wildfires that decimated the California landscape significantly increased ozone and $PM_{2.5}$ emissions there, coinciding with the latter part of the COVID –19 pandemic (Liu, 2021). This would then suggest the potential for long-range transmission of pollutants from these wildfires to Chicago. wildfires can cause increases in pollutant concentrations far from the source (Cottle et. al., 2014). However, the geographical distance between Northbrook and Chicago is small compared to the distance from California. Any influence that affected the ComEd site should also be seen at the Northbrook site. Also, the fires were greatest during the summer months, not during the months of March through April. But further studies would be beneficial to ascertain the impact of distant wildfires on Chicago air quality. This study did not incorporate the potential for long-range transport of air pollutants from California wildfires as a confounding factor in analyses.

Ultimately our initial results support the hypothesis that long-haul transport of goods contributed to why Chicago did not observe healthy air quality conditions when compared to other cities around the world during the peak of COVID-19 lockdowns, but it should be kept in mind that this result needs further exploration and testing.

A major strength of this study was the ability to use large amounts of data to conduct our analyses. This allowed us to establish a baseline for the $PM_{2.5}$ and ozone emissions at the three sites with high levels of confidence to which we could then compare the "natural experiment" of COVID to. Furthermore, the ability to conduct this study remotely during the height of the COVID-19 pandemic allowed for the prioritization of safety. By the nature of conducting remote work and the limitations to personal resources, this study was unsurprisingly also limited. The scope of this study was kept within the bounds of air pollution in Chicago. Other factors such as analyzing transportation data in conjunction with Chicago air pollution has not yet been explored. Due to this, the conclusions we can make related to these other factors are necessarily speculative. In conducting this study again, while we purely focused on Chicago, incorporating other cities with comparable population size and population distribution to Chicago would provide insight into how much the long-haul transport may beresponsible for the lack of air quality improvements.

As mentioned previously the direct comparison to a nearby suburb, Northbrook, that did experience improvements in air quality due to COVID-19 lockdown measures, supports the long-haul transport hypothesis. The issue within the city of Chicago then becomes more complex in terms of environmental justice and the populations exposed to the greatest $PM_{2.5}$ concentrations. These populations in the city on the South and West sides are exposed to greater concentrations of air pollutants than other populations in the city. It has even been reported that approximately 25% of all freight trains and 50% of all intermodal trains in the United States pass through Chicago (Freight). Additionally, the ComEd monitor site is less than one mile from a major rail transportation hub on the South-West side of the city, further providing evidence for the environmental injustices in terms of air quality in different areas of the city, primarily in lower-income, minority communities. These tensions between economic development and environmental contamination and justice continue to be a primary issue in many communities, especially in regard to bringing new air pollution to communities (Nolan, 2021). This study then can be used for improving air quality as it relates to populations that are most affected yet not responsible for the pollution.
Questions for future research involve: what is the distribution of air pollutants in the neihborhoods of Chicago, what will reopening and returning to normalcy look like in terms of air pollution, and to what extent has the lack of air quality improvement increased COVID-19 mortality? These research questions on their own can then serve as the backbones of further studies to take advantage of the large-scale "natural" experiment of the COVID-19 pandemic and the implications of the stay-at-home orders.

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